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OPTIMIZATION OF PROCESS PARAMETERS FOR POCKET MILLING OF AL7075 USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Nowadays, the high quality of surface finish is in demandto meet the market requirements. Manufacturing industry has many complex processes that vary in nature. The current paper describes the development of a model for pocket milling on Al7075 using Response Surface Methodology (RSM). This model gives mathematical relationships in terms of Cutting speed, Feed and Step Over for Follow periphery and Zigzag tool path strategies. The Surface Roughness (SR) is predicted with these relationships and compared with the measured surface roughness of the machined components. The error observed is less than 5% between predicted and measured values.

KEYWORDS: Pocket Milling, Aluminium, RSM, Tool Path Strategy & Optimization

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Original Article

INTRODUCTION

Surface integrity is one of the most influencing factors to accept the quality of a product in many manufacturing components. In modern manufacturing world with computer numerical control machines, achieving surface quality is not a much difficult task. But with trial and error methods, much of the valuable production time and material are wasted. To overcome this problem, optimization of machining parameters is necessary. Even though, there are several factors that affect the surface finish of a product, Speed, Feed, and Depth of cut are found to be the most influencing factors on surface roughness. Alauddin et al. [1] have developed a surface roughness model for milling 190BHN steel with Response Surface Methodology. In their study, the feed was found to be the most dominating factor for surface roughness. Proper selection of cutter path strategies in pocket milling saves machining time and cost. It also helps in improving surface quality [2]. In pocket milling, step over and tool path strategy also play important roles in obtaining the required surface finish [3]. Aluminium and its alloys are the commonly used materials in many fields of engineering. Their properties such as light weight, ease of machinability, corrosion resistance etc., make them qualify for diversified applications. In molding industry, surface finish is considered as one of the important parameters for manufacturing plastic components [4]. G1-continuous spiral path is employed by Held and Spielbergr[5], by using "POWERAPX" Package for the generation of tool path in 2D pocket milling. Michel Bouard etal. [6] explained a new method for tool path computation. In the current study, uniform cubic B-spline curves are applied to model surface roughness with an optimization algorithm. Ali et al. [10] experimented on hardened material AISI H13 tool steel to predict surface machined quality. Response Surface Methodology (RSM) Model was used to design the prediction model with parameters generated using Central Composite Face (CCF) methods. Evolutionary algorithms also applied to optimize the cutting conditions for better surface finish [6-8]. Effect of tool path strategies and pocket geometry on

surface roughness, machining time and cutting forces is measured by PE Romero et al. [11]. An Artificial neural network model was developed to predict the optimal parameters for minimum surface roughness value [12]. Wong etal.[14] studied the influence of process parameters for face milling of Semi solid Al7075 on surface quality and tool wear using factorial designs. Hashmi et al. [15] used Response surface methodology for optimizing process parameters in high-speed milling of titanium alloy. Nurhaniza et al. [16] analyzed the influence of machining parameters in CNC end milling operation for machining CFRP aluminium with PCD tool. In high-speed machining of 2D pockets, various tool path strategies can be employed.

From the above review, it is observed that most of the researchers concentrated on speed, feed and depth of cut as these are dominating factors in obtaining the required surface roughness value. In the current work, a mathematical model is developed using RSM to optimize the speed, feed and step over. The combination of machining parameters for obtaining optimal surface roughness is also determined in the study for machining Al7075 for both the tool path strategies.

METHODOLOGY

A response surface design is a set of advanced Design of Experiment (DOE) techniques that help in better understanding and optimization of the responses. Response Surface Methodology (RSM) is often used to refine models after determining important factors using factorial designs. RSM is one of the statistical methods for finding a relation between various input parameters and output parameters. It is an efficient tool to overcome the interaction effects. RSM involves more experimentation with less cost and takes closer to global minimum. There are two main types of response surface designs.

Central Composite Designs (CCD)

It is applicable to fit a full quadratic model. CCD is used when number of factors involved for sequential experimentation is more.

Box-Behnken Designs

Box-Behnken designs, usually have fewer design points than central composite designs, thus, they are less expensive to run with the same number of factors. They can efficiently estimate the first-and second-order coefficients; however, they can't include runs from a factorial experiment. Box-Behnken designs always have 3 levels per factor and never include runs where all factors are at their extreme setting, such as all the low settings.

EXPERIMENTAL FACTORS AND MATERIAL

Design of experiments is an important tool to select the number of experiments to be conducted for the study. The response that is to be optimized is expressed in terms of unknown relation with the selected process parameters, called design factors. There are several factors that can be considered for pocket milling. But in the present study, the factors considered are Speed, Feed, and step over. The levels for the factors are considered based on literature review, machine specifications and material properties. Three levels for three factors with codes are defined in Table1.

Table 1: Assignment of Levels to Factors

Symbol	Machining Parameters	Units	Level 1	Level 2	Level 3	Observed Values
S	Spindle Speed	RPM	3000	4000	5000	SR(μm)
F	Feed	mm/min	500	1500	2500	
SO	Step over	%	20	40	60	
CODE			-1	0	1	

The number of design runs is decided using Box-Behnken design. As the number of factors is three with three levels, the experimental runs are given in Table2 in a coded manner using Design Expert 11.

Table 2: Order of Experimental Run

Run Order	Std. Order	Speed	Feed	SO
1	8	1	0	1
2	7	-1	0	1
3	5	-1	0	-1
4	2	1	-1	0
5	9	0	-1	-1
6	3	-1	1	0
7	1	-1	-1	0
8	13	0	0	0
9	6	1	0	-1
10	11	0	-1	1
11	10	0	1	-1
12	12	0	1	1
13	15	0	0	0
14	4	1	1	0
15	14	0	0	0

Material

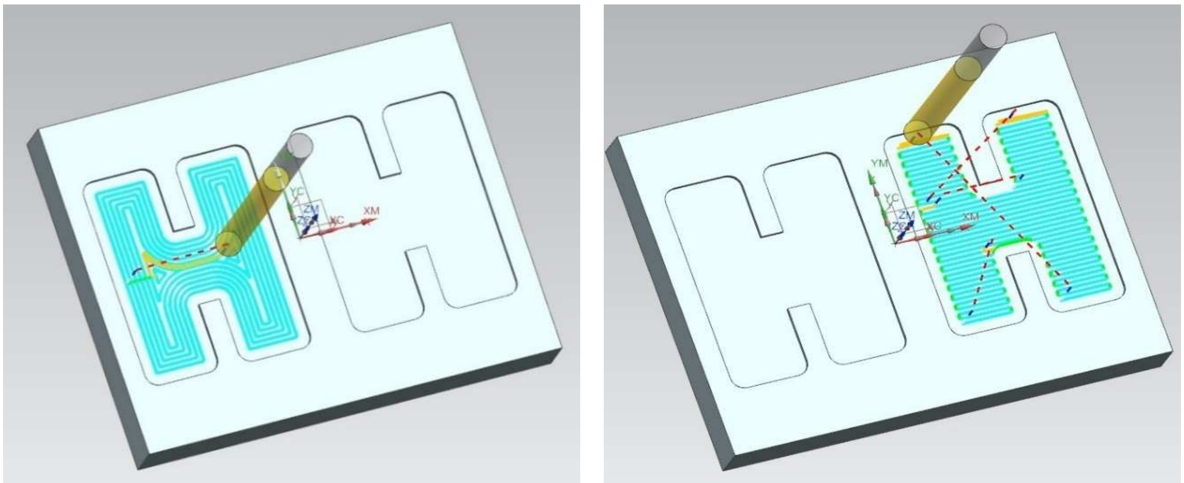
Al7075 with a specimen size of 80mm x70mm with a depth of 10mm is used in the present study. Al7075 is an aluminium alloy, with Zinc as primary constituent. It has good fatigue strength, when un-heat-treated; it has high tensile and yield strengths. But, it has low weldability and average machinability. Because of high strength, thermal properties, low density, specific strength Al7075 finds applications in marine, air craft building, automotive and molding industry. The composition of selected material is given in Table 3.

Table 3: Chemical Composition of Al7075

Element	Aluminium(Al)	Zinc(Zn)	Magnesium(Mg)	Copper(Cu)	Others
% composition by wt.	90-92%	5.6–6.1%	2.1–2.5%	1.2–1.6%	Less than 0.5%

SIMULATION AND EXPERIMENTAL DETAILS

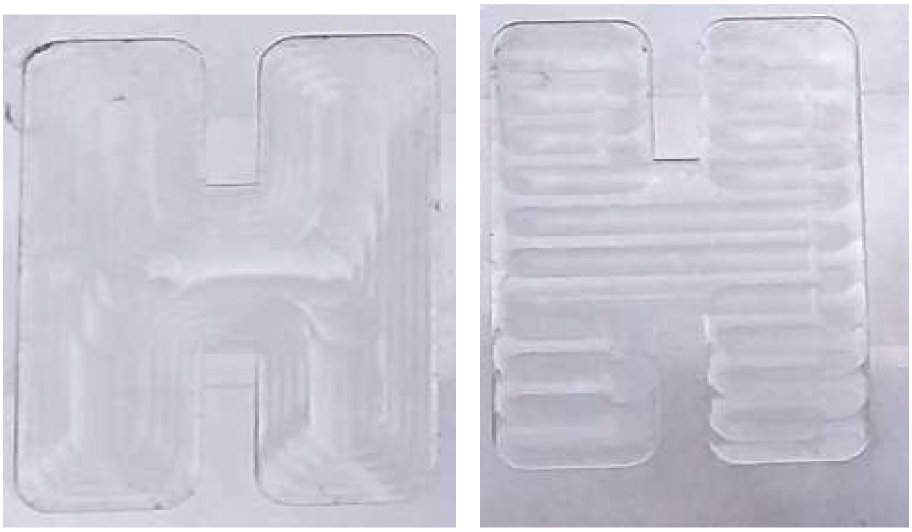
The profile of the pocket that is to be cut on the workpiece surface is modelled with Siemens NX software. The tool path strategies are simulated on the pocket geometry as shown in figure 1, and NC code was generated for each model.



a) Follow Periphery Tool Path Strategy **b) Zigzag Tool Path Strategy**

Figure 1: Tool Path Strategy for Pocket Milling

AMC MCV-350 model CNC Vertical Axis Machining center with Fanuc series controller is used to generate the pockets. A four-flute tungsten carbide coated tool with 6mm diameter is used for machining. The experiments are conducted with coolant to reduce the thermal effects while machining. The surface roughness is measured using SJ201P Surf test. Five samples for each experiment and the average of the results are considered for analysis. The specimen after machining is shown in Figure 2. Figure 2(a) shows follow periphery tool path where as Figure 2(b) represents Zigzag strategy.



a) Follow Periphery Tool Path Strategy **b) Zigzag Tool Path Strategy**

Figure 2: Tool Path Strategy for Pocket Milling

RESULTS AND DISCUSSIONS

It was found that the surface roughness decreases with an increase in spindle speed, increases as feed rate and step over increases. The variation in the surface roughness for different combinations of speed, feed and step over is represented in Table 4. Using these experimental results, empirical equations have been obtained to estimate surface roughness with the significant parameters considered for experimentation i. e. cutting speed, feedrate and step over.

Table 4: Surface Roughness Values for the Two Tool Path Strategies

Run	Speed (RPM)	Feed (mm/min)	SO (%)	Measured SR (FP) µm	Measured SR (ZZ) µm
1	-1	-1	0	1.277	0.966
2	0	0	0	1.425	1.522
3	0	0	0	1.425	1.506
4	-1	0	1	0.792	1.361
5	-1	0	-1	1.103	0.767
6	1	0	1	1.322	0.98
7	0	-1	1	0.938	1.033
8	1	1	0	1.528	0.938
9	1	0	-1	1.088	0.978
10	0	0	0	1.384	1.5
11	1	-1	0	1.266	1.251
12	0	1	-1	0.79	0.834
13	-1	1	0	0.934	1.229
14	0	-1	-1	1.155	0.949
15	0	1	1	1.112	1.137

The second-order response equations have been fitted for the response variable SR, for the two tool path strategies separately. The equations are developed using Design Expert 11 as follows:

- **For Follow-periphery tool path strategy**

$$SR = 1.411+0.137375S-0.36375F+0.006SO+0.151SF+0.13625SSO+0.13975FSO-0.03875S^2-0.12125F^2-0.296SO^2 \quad (1)$$

- **For Zigzag tool path strategy**

$$SR = 1.51-0.015S-0.0007F+0.1227SO-0.1579SF-0.148SSO+0.055FSO-0.1979S^2-0.2301F^2-0.2907SO^2 \quad (2)$$

The effect of cutting parameters on the surface roughness, under different machining conditions for the two tool path strategies is as shown in Figure 3. It is observed that the variation in surface roughness for follow pheriphery is more when compared to that of variation in zigzag strategy. From the graph it is evident that, though some combinations of the factors show less variation between the two strategies, The surface roughness values for both strategies are predominent.

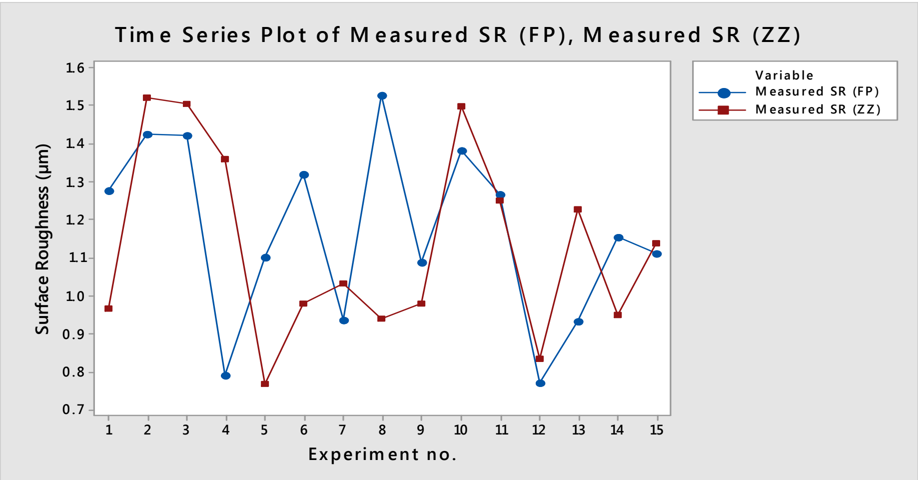


Figure 3: Surface Roughness plot for Follow Periphery and Zigzag tool Path Strategies

From the experimental results, it is observed that for follow periphery tool path, the minimum surface roughness value is obtained at medium speed, high feed and low stepover, where as for zigzag strategy low speed, medium feed and low stepover gives minimum surface roughness value.

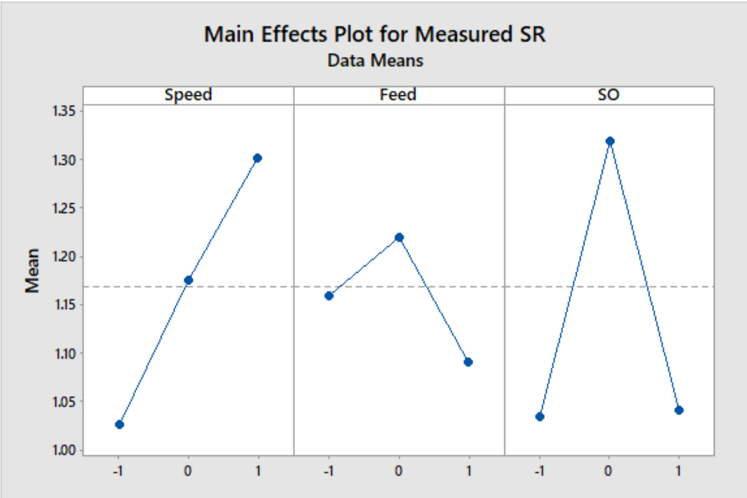


Figure 4: Main Effects Plot for Measured Surface Roughness in Follow Periphery Tool Path

From the Figure 4, it can be understood that we can obtain minimum surface roughness at minimum speed, maximum feed and minimum step over. The effect of speed is more as the slope is steeper when compared to other parameters viz. feed and step over. The effect of change in step over is also considerable, as it shows much variation in the surface roughness value. The rate of change of surface roughness with respect to change of feed is less when compared to speed and feed.

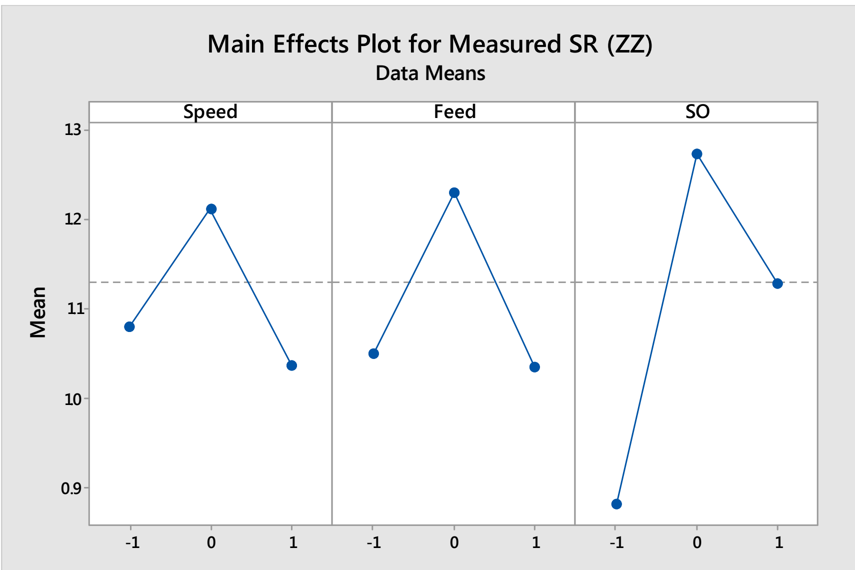


Figure 5: Main Effects Plot for Measured Surface Roughness in Zigzag Tool Path

The main effects graph for Zigzag tool path is shown in Figure 5. It indicates that higher speed, higher feed and lower stepover gives minimum surface Roughness. It is observed that, out of the three parameters, stepover has definite influence on the surface roughness in this tool path strategy.

The roughness value is also predicted with the equations 1 and 2. The error between the predicted and the measured values of the surface roughness is given in table 5&6 for the chosen tool path strategies.

Table 5: Predicted Surface Roughness Values for the Follow Periphery Tool Path Strategy

Run	Speed	Feed	SO	Predicted SR (µm)	% Error between Measured and Predicted Values
1	-1	-1	0	1.2986	1.77116
2	0	0	0	1.41	1.05263
3	0	0	0	1.41	0.7741
4	-1	0	1	0.8061	1.7803
5	-1	0	-1	1.0717	2.83772
6	1	0	1	1.3535	2.38275
7	0	-1	1	0.9014	3.90192
8	1	1	0	1.5056	1.46597
9	1	0	-1	1.0739	1.29596
10	0	0	0	1.41	1.87861
11	1	-1	0	1.2714	0.42654
12	0	1	-1	0.8266	4.63291
13	-1	1	0	0.9288	0.55675
14	0	-1	-1	1.164	0.77922
15	0	1	1	1.1032	0.79137

It is observed from Table 5, that the error in the predicted value of the surface roughness is less than 5% when compared with the measured value in follow periphery.

Table 6: Predicted Surface Roughness Values for the Zigzag Tool Path Strategy

Run	Speed	Feed	SO	Predicted SR (µm)	% Error between Measured and Predicted Values
1	1	-1	0	1.2331	1.2331
2	-1	1	0	1.2481	1.2481
3	0	-1	1	1.0508	1.0508
4	0	0	0	1.51	1.51
5	-1	0	1	1.3213	1.3213
6	0	0	0	1.51	1.51
7	1	1	0	0.9159	0.9159
8	1	0	-1	1.0729	1.0729
9	1	0	1	0.9819	0.9819
10	-1	-1	0	0.9337	0.9337
11	0	-1	-1	0.9288	0.9288
12	0	0	0	1.51	1.51
13	0	1	1	1.1594	1.1594
14	0	1	-1	0.8174	0.8174
15	-1	0	-1	0.7663	0.7663

It is observed from the Table 6, that the error in the predicted value of the surface roughness is less than 5% when compared with the measured value in Zigzag Strategy.

Confirmation experiments were conducted for both the tool path strategies based on main effects plots for three times. That is, for Follow periphery low speed, high feed and low step over and for Zigzag high speed, high Feed and low step over. The obtained results are compared to that of predicted values and found that the error is within 5% limit.

Table 7: Confirmation Test Results

Tool Path	Expt. No	Confirmation Test Results		% Error
		Predicted	Measured	
Follow periphery	1	0.6338	0.6326	0.1897
	2	0.6338	0.6319	0.3007
	3	0.6338	0.6298	0.6351
Zigzag	1	0.6224	0.6199	0.4033
	2	0.6224	0.6201	0.3709
	3	0.6224	0.6196	0.4519

Interaction plots for followperiphery tool path strategy is presented in Figure 6. It is observed that the variation in surface roughness is more when speed is at middle level, by varying either feed or step over. Similarly, for lower speed level, variation of feed gives decreased surface roughness and variation of Step over (SO) shows much more decrease. But at higher speed level, change in feed shows drastic increase in Surface roughness, whereas for SO, even though there is increase up to mid-level, at higher level, there is decrement by a little amount.

Figure 6: Interaction Plot between Surface Roughness Speed feed and Step Over for follow Periphery Tool Path Strategy

The interaction plot for zigzag strategy, shown in Figure7 reveals that the middle level combination of the parameters shows high surface roughness value, but higher speed, higher feed and lower step over gives minimum surface Roughness.

Figure 7: Interaction Plot between Surface Roughness Speed feed and Step Over for Zigzag Tool Path Strategy

CONCLUSIONS

In the present study, a mathematical model was developed, to optimize the Process parameters for minimizing surface roughness, using Response Surface Methodology. Two tool path strategies viz. follow periphery and Zigzag are used for machining the profile. The predicted surface roughness values are compared to the experimentally measured values. The following observations are evident from the results:

- For the range of the parameters considered, variation of surface Roughness is high in follow periphery when compared to that of zigzag strategy.
- For follow periphery, the cutting speed is the dominating factor, the surface roughness increases rapidly with increase in speed. For Zigzag tool path strategy, Step Over shows more dominance than Speed and Feed, as the variation in surface roughness value is higher when compared to that of speed and feed rate.
- The observed error between predicted and measured surface roughness values is within the 5%.

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